10.3 OTHER TANKS

10.3.1 UNDERGROUND TANKS

Guidelines for considering earthquake loading for the design and evaluation of underground storage tanks can be found in Reference 29 ("Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Tanks and Appurtenances", BNL 52361). This document was prepared for high-level waste tanks and specifically covers the primary tank, secondary liner, concrete vault, transfer piping, and the other components required to maintain the confinement function of a tank farm. The guidelines are developed primarily for double-shell tanks since it is expected that all new tanks will be double-shell structures. However, these guidelines are also generally applicable to single-shell tanks.

The design and evaluation guidelines in Reference 29 include a definition of the design basis earthquake ground motion, simplified methods for determination of soil-structure and liquid-structure interaction effects, analytical techniques for evaluating seismic demand, and criteria for assessing structural capacity. Table 10.3.1-1 provides a road map to the various subjects addressed in Reference 29. The abstract states that these guidelines reflect the knowledge acquired in the last two decades in the areas of defining the ground motion and calculating hydrodynamic loads and dynamic soil pressures, and other loads for underground tank structures, piping, and equipment. Interpretation and implementation of the guidelines are illustrated through examples.

Table 10.3.1-1 Use of "Seismic Design & Evaluation Guidelines for the Department of Energy High-Level Waste Tanks & Appurtenances" (Ref. 29)

Subject Matter	Chapter and/or Appendix from Reference 29
Seismic Design and Evaluation Criteria	Chapter 3
Evaluation of Tank Response	
Hydrodynamic Effects	Chapter 4
Liquid Viscosity Effects	Appendix B
Soil-Structure Interaction	Chapter 6 and Appendix H
Effect of Top Constraint	Appendix C
Seismic Response Example	Appendix G
Evaluation of Tank Capacity	
Seismic Capacity	Chapter 5
Inelastic Energy Absorption	Appendix A
Buckling of Tanks	Appendix F
Effects of Sloshing Striking the Roof	Appendix D
Dimension Tolerance and Fabrication Details	Appendix E
Associated Structures and Equipment	
Underground Piping (Section 10.1.2)	Chapter 7 and Appendix I
Equipment Qualification	Chapter 8

As described in Chapter 3 of Reference 29 (see Table 10.3.1-1), the seismic guidelines for underground storage tanks are based on the same target performance goals upon which general seismic design and evaluation criteria for Department of Energy structures, systems, and components as given in DOE-STD-1020 (Ref. 6) are based. Deterministic, pseudo-linear seismic evaluation procedures are provided that are based on the DOE target performance goals. The document recognizes that there may be situations where explicit non-linear dynamic analysis of structures or soil columns may be necessary. It also recognizes cases, such as liquefaction analysis, where there may not be existing capacity standards consistent with the deterministic procedures. For these situations, a more general approach for complying with the target performance goals is discussed in which alternative design or evaluation techniques may be employed.

In addition to general seismic design and evaluation criteria, many subjects specifically addressing issues pertinent to underground storage tanks are covered by Reference 29 as illustrated by Table 10.3.1-1. In general, these subjects include evaluation of hydrodynamic effects in tanks, seismic capacity of tanks, evaluation of soil-vault interaction, and underground piping and conduits. Each of these areas is briefly described in the following paragraphs.

A critical element in the analysis of the seismic response of the tank-liquid system is the evaluation of the hydrodynamic pressures exerted against the tank wall and base. Once these pressures have been established, the corresponding forces and stresses in the tank may be determined with relative ease. Methods of evaluating hydrodynamic pressures for horizontal, rocking, and vertical components of earthquake ground motion are presented. In addition, sloshing motion of the free liquid surface is considered. These items are addressed in Chapter 4 and Appendix G of Reference 29 (see Table 10.3.1-1). Of special interest for waste storage tanks are the effects of inhomogeneous liquids within the tank or the influence of liquid viscosity on hydrodynamic effects which is addressed in Appendix B of Reference 29.

Assessment of the seismic capacity of tanks in Reference 29 considers observed failure modes for tanks in past earthquakes. Flat bottom vertical liquid storage tanks have sometimes failed with loss of contents during strong earthquake shaking. For tanks with radius to wall thickness ratios greater than about 600 or tanks with minimal or no anchorage, failure has often been associated with rupture of the tank wall near its connection to the base, due either to excessive tank wall buckling or bolt stretching and excessive base plate uplift. Both failure modes are primarily due to the dynamic overturning moment at the tank base from fluid pressure on the tank wall. Other common failure mode have been breaking of piping connected to a tank as a result of relative movement and severe distortion due to a soil failure (soil liquefaction, slope instability, or excessive differential settlement). Other failure modes, which are of much lesser importance either because of their general lack of occurrence or less severe consequences, but which deserve some attention, are: tank sliding, excessive hoop tensile stresses due to hydrodynamic pressures on the tank wall, damage to the roof due to insufficient freeboard for fluid sloshing, and damage to internal attachments from lateral and torsional fluid movements. Tank capacity evaluation is addressed in Chapter 5 and Appendices A, F, D, and E of Reference 29 as shown in Table 10.3.1-1.

Important considerations for soil-vault interaction are evaluation of the seismic input motion to the support points of the tank and the seismically induced pressures on the walls of the vault. Evaluation of soil-vault (soil-structure) interaction must consider the vertical spatial variation of the free field ground motion and that the motion of the vault may differ from the free field motion. Guidelines for necessary soil properties and evaluation of soil structure interaction effects applied to underground tanks are presented in Chapter 6 and Appendix H of Reference 29.

Most underground waste process piping systems are encased (or double containment) piping systems. The inner pipe serves to transport the wastes and maintain the pressure boundary and the outer pipe provides secondary containment and is in direct contact with the surrounding soil. The design of underground piping systems and conduits must demonstrate the ability of the piping system to withstand strains and stresses caused by potential seismic movement of the surrounding soil in conjunction with stresses induced by other concurrent loads. Guidelines are provided to consider different aspects of seismically induced ground movements including: (1) abrupt relative displacements of the ground at faults; (2) ground failure of relatively large areas caused by liquefaction, landslides, gross surface movements, or collapse of voids at depth; (3) transient deformation of the ground during the earthquake due to wave passage effects; (4) inertial response of the inner piping system in response to induced movements of the outer piping; and (5) transient movements of anchor points or buildings connected to buried facilities. As shown in Table 10.3.1-1, underground piping is addressed in Chapter 7 and Appendix I of Reference 29.

10.3.2 CANISTERS AND GAS CYLINDERS

This section describes general guidelines that can be used for evaluating and upgrading the seismic adequacy of canisters and gas cylinders which are included in the Seismic Equipment List (SEL). Guidelines in this section cover those features of canisters and gas cylinders which experience has shown can be vulnerable to seismic loadings.

Unanchored compressed gas cylinders will tip over at very low levels of ground shaking. If the reducing valve should snap off, the canister may become a high speed missile. In addition, escaping gas may represent a potential fire, explosion, or toxic gas hazard to nearby personnel.

Compressed gas cylinders often have a single safety chain located about mid-height (Figure 10.3.2-1). A single chain is not sufficient to prevent tipping during an earthquake. Examples of properly anchored cylinders are presented in Figures 10.3.2-2 and 10.3.2-3. In these figures, the gas cylinders have upper and lower safety chains, or restraints.

In the event of an earthquake, poorly restrained canisters and gas cylinders may fall and roll, spilling their contents, causing damage to other equipment, and/or injuring personnel. Methods of restraining them, including providing positive anchorage to a wall, storing them in well braced and anchored racks, or storing them horizontally on the floor, are shown in Figure 10.3.2-4. The supports for the canisters should be attached to walls that have adequate capacity to resist the seismic demand from the canisters. Adequate capacity typically results from two levels of support or a structural storage system that restrains moments.

Figure 10.3.2-1 Compressed Gas Cylinder that is Inadequately Anchored with a Safety Chain Located at Midheight (Figure 4-55 of Reference 60)

Figure 10.3.2-2 Adequately Anchored Compressed Gas Cylinder (Figure 4-57 of Reference 60)

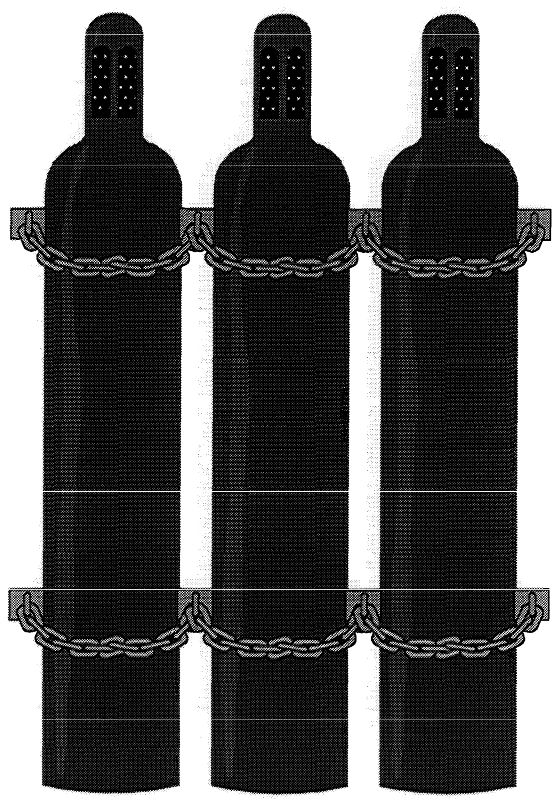


Figure 10.3.2-3 Upper and lower restraints are required for gas bottles.

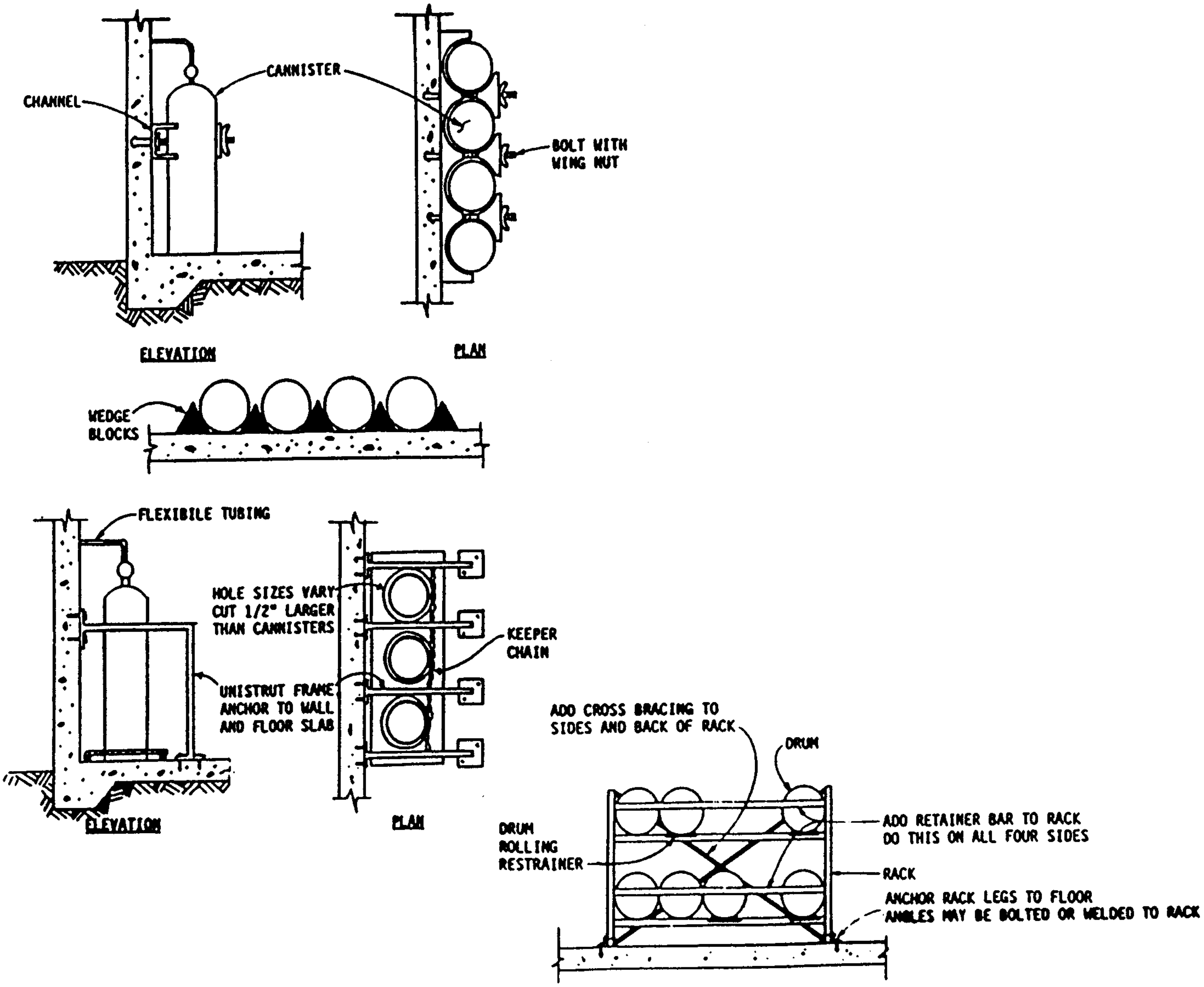


Figure 10.3.2-4 Approaches for Anchoring Canisters (Figure 4-56 of Reference 60)

10.4 DUCT SYSTEMS

10.4.1 HVAC DUCTS

This section is the "Procedure for the Seismic Evaluation of Steel HVAC Duct" (Ref. 28) which was developed by the Westinghouse Savannah River Company and is based on information in Reference 107. It is limited to applications involving existing duct systems. For new design, the engineer is referred to other methods documented in References 108, 109, and 110. Additional information is contained in References 111 and 112.

10.4.1.1 Scope

This procedure provides seismic evaluation rules for existing rectangular or round steel HVAC duct. The objective of this evaluation procedure is to ensure a high confidence of acceptable seismic performance for the following:

- duct structural integrity
  - material condition
  - joint, seam, and stiffener design
  - vertical and horizontal support bracing
  - heavy components and appurtenances
  - stiff branches
- duct pressure boundary integrity (if applicable)
  - joint, seam, and stiffener design
  - duct panel stress
  - duct support bearing (point contact)
  - flexible bellows
- duct support integrity
  - material condition
  - seismic capacity vs. demand
  - support anchorage
  - support details (load path)
- seismic interactions

The duct system seismic evaluation includes facility walkdown reviews and limited analytical reviews of bounding sample configurations. The relationship and typical sequence of these reviews is shown in a logic diagram in Figure 10.4.1-1.

Fans (including louvers) and air handlers (including dampers) are covered in Sections 8.2.10 and 8.2.9, respectively.

Duct mounted dampers that are not part of the fan or air handler assemblies and floor mounted filter housings and plenums must be evaluated separately and are not covered by this procedure.

10.4.1.1.1 Industry Standards

"HVAC Duct Construction Standard, Metal and Flexible", SMACNA (Ref. 113)

"Rectangular Industrial Duct Construction Standards", SMACNA (Ref. 114)

"Round Industrial Duct Construction Standards", SMACNA (Ref. 115)

10.4.1.1.2 Duct Loads

(a) Duct weight

(b) Coating and insulation weight

(c) Positive (outward) or negative (inward) uniform pressure. Typically expressed in inches of water gage (wg), as a differential pressure relative to atmosphere (1 atmosphere = 0 wg and 1 wg = 0.0361 psig).

(d) Weight of particulate accumulation in the duct.

(e) Weight of workmen or implements resting from time to time on the duct.

(f) Forces due to wind, for outdoor duct.

(g) Forces due to seismic events.

(h) Vibration from system operations.

Loads (a) through (f) are addressed in the SMACNA design standards.

Seismic loads (g) are evaluated by this procedure which is based on design standards, testing and seismic experience as documented in Reference 107.

Vibration loads (h) are typically evaluated and resolved after system start-up.

10.4.1.1.3 Seismic Review Team

The seismic review team shall consist of a minimum of 2 engineers certified in the use of the DOE Seismic Evaluation Procedure (see Section 3.2) and knowledgeable in the design requirements of the SMACNA standards. They shall document their review on Screening Evaluation and Work Sheets (SEWS) as described in this procedure. Each evaluation attribute shown on the SEWS form is described in Section 10.4.1.2 through 10.4.1.6 of this procedure.

10.4.1.1.4 Duct System Boundary

The duct system boundary establishes the scope of the configuration to be evaluated. These boundaries are determined based on consideration of system requirements and operational needs during or following a seismic event. For example, the HVAC system performance requirements following an earthquake may be to support environmental confinement of hazardous materials. In this case, pressure boundary integrity is important. The HVAC evaluation boundaries may terminate at system isolation points such as dampers. Furthermore, the evaluation scope might be limited to portions of the system that support filtration (e.g. HEPA which is also discussed in Section 10.2.1) and effluent exhaust.

In some cases, the performance objective of the HVAC system may be to convey air for the comfort and safety of building personnel. In this situation, duct structural integrity is the primary objective (instead of a high degree of pressure retention).

A Screening Evaluation Work Sheet (SEWS 10.4.1) may encompass a single run of duct, a duct system (several runs of duct with the same operating parameters) or a group of duct systems. The SEWS should describe, by sketch or system identification, the scope of ducts covered.

10.4.1.1.5 Evaluation Objectives (Pressure Boundary/Structural Integrity)

Where only structural integrity is required, some leakage in or out of the duct is allowed, provided the duct retains its spatial configuration and does not fall. This procedure addresses the seismic structural integrity of the duct and its support system together with a review for potential seismic interactions.

Where pressure boundary integrity is required, the duct wall can not be breached and the duct joints and seams must remain pressure tight. An example is that of a HVAC duct that is used for conveyance of hazardous effluent gas to a HEPA filter. In general, confinement HVAC systems are configured so that the operating pressure for the hazardous gas is maintained at a negative pressure relative to the environment of the duct exterior. The safety requirements for such a configuration have very limited tolerance for duct leakage so as to preserve the duct system effectiveness and efficiency. Consequently, this duct would probably be classified as a safety related item (PC3 or PC4). This procedure augments the duct structural integrity evaluation requirements with additional criteria to provide a high degree of confidence that pressure boundary integrity will be maintained during a seismic event.

10.4.1.1.6 Functionality Requirement

HVAC duct systems may be required to function during a seismic event. In this case, spurious changes of equipment condition (such as accidental closing or opening of dampers, or loss of controls) are not permitted to occur.

HVAC duct systems may be allowed to malfunction during the period of seismic vibration, provided it can be reset (remotely or by local manual controls) to function after the seismic event.

10.4.1.1.7 Bounding Sample Evaluation

A group of duct systems may be evaluated based on a worst-case bounding sample review. For each attribute, the Seismic Review Team must select the worst-case configurations. For example, the review for stiffener spacing may be based on panels having the largest width, thinnest gage, greatest distance between stiffeners with the smallest section properties. The basis for the selected bounding sample(s) should be documented on the SEWS form.

10.4.1.2 Evaluation for Structural Integrity

10.4.1.2.1 Duct Free of Damage, Defects, Degradation

The HVAC duct system network should be visually inspected for damage, defects, and degradation. The inspection should also identify suspect repairs, missing parts, broken joints, poor workmanship and significant corrosion, particularly at duct joints.

10.4.1.2.2 Duct Material and Stiffeners Comply with SMACNA

A visual inspection of the ducts should confirm that the duct material, stiffeners and joints are in accordance with SMACNA (Ref. 113, 114, and 115).

In particular, the following attributes must be verified:

a. Materials should be rolled steel (below 650°F operating temperature), galvanized steel (below 400°F), or stainless steel.

b. Stiffeners should comply with SMACNA: steel shapes (Ref. 113 Page 1-23 and Ref. 114 Page 7-56 to 58), angle or bar reinforcement for round ducts (Ref. 115 Page 4f-2). Fastening of the stiffener to the duct should be by tack weld, spot weld, bolt, screw or rivet, 12" max. spacing (Ref. 113 Page 1-48).

10.4.1.2.3 Duct Joints and Seams Comply with SMACNA

Joints and seams should conform to SMACNA standard configurations, and be positively attached, excluding friction or riveted joints. Acceptable transverse joint configurations are: Ref. 113 Page 1-35; Ref. 114 Page 8-7; Ref. 115 Pages 5-4 and 5-11 excluding sleeved (Figure 3), riveted (Figure 4) and draw band (Figure 5) joints. Acceptable longitudinal seam configurations are groove weld and fillet weld (Ref. 114 Pages 8-1 through 8-6; Ref. 113 Page 3-5), and lock type (Ref. 113 Page 1-40) excluding riveted seams.

10.4.1.2.4 Duct Meets Support Span Criteria

10.4.1.2.4.1 SMACNA Rules

SMACNA provides rules for the spacing of duct supports (Ref. 113 Page 4-3, Ref. 114 Page 9-7, and Ref. 115 Page 7-3), based on a maximum allowable bending stress in the duct wall of 8 ksi for rectangular duct and 10 ksi for circular duct.

For seismic loads, the same spacing criteria must be met, however an increase of the allowable bending stress by 33% is allowed provided the duct joints are type T-17 to T-24 (Ref. 113 Page 1-35).

10.4.1.2.4.2 Computing the allowable support span length for rectangular duct:

The SMACNA approximation for rectangular duct section properties is based on four 2" corners (Ref. 114 Page 9-7) and a bending stress ($\sigma = w L^2 / 10$ which is based on the average of simply supported and built-in moment). For duct with uniformly distributed load, the allowable span between consecutive vertical supports can be expressed as:

$$L = [80 F_b / (H + W) \rho K_R]^{1/2}$$

where:

F_b	=	allowable bending stress (psi) [typically 8000 psi for rectangular duct]
H,W	=	height, width of duct (in) (see Figure 10.4.1-2)
ρ	=	equivalent density of duct material (lb/in^3). (Note - Include insulation and reinforcement mass contribution).
K_R	=	parameter for rectangular duct in Section 10.4.1.6.1 (1/in^2)

10.4.1.2.4.3 Computing the allowable support span length for circular duct:

The SMACNA approximation for circular duct is based on a bending stress $\sigma = w L^2 / 10$. For circular duct with uniformly distributed load, the corresponding allowable span between consecutive vertical supports can be expressed as:

$$L = (5 F_b D / 2 \rho K_c)^{1/2}$$

where:

F_b	=	allowable bending stress (psi) [typically 10,000 psi for circular duct]
D	=	duct diameter (in)
ρ	=	equivalent density of duct material (lb/in^3). (Note -Include insulation and reinforcement mass contribution).
K_c	=	parameter for circular duct in Section 10.4.1.6.2 (dimensionless).

10.4.1.2.4.4 Effect of concentrated weights

Heavy in-line components, such as unsupported in-line dampers subject to seismic accelerations, exert an additional bending moment on the duct. The allowable support span must be reduced accordingly, to limit the bending stress to within the allowable F_b.

Beam equations may be used to superimpose the distributed weight and the concentrated weight stress (see Section 10.4.1.6.3 for additional guidance).

10.4.1.2.5 Duct Guided Against Sliding Off Supports

Seismic experience indicates that HVAC duct can fail if it slides off its supports. The duct must be secured, by tie-downs or stops, if it can slide and fall off its supports.

10.4.1.2.6 Heavy In-Line Components Properly Restrained

Components mounted in-line on the duct work include fans, coolers, dryers, dampers, motor operators to dampers, and blowers.

In-line equipment must be positively attached to ductwork. Duct connections to heavy in-line components must be evaluated for structural capacity.

Support spans are to be reduced for heavy in-line components as discussed in Section 10.4.1.2.4.4.

In-line floor mounted equipment on vibration-isolation pads requires a separate evaluation based on failures recorded in the experience database. Guidance in performing this review is given in Chapter 6.

10.4.1.2.7 Appurtenances Properly Attached

Appurtenances to ducts include dampers, louvers, diffusers, and screens. Appurtenances must be positively attached to duct work (such as screwed or riveted) as opposed to slipped into place.

Duct connections to heavy cantilevered appurtenances must be evaluated for structural capacity.

10.4.1.2.8 No Stiff Branch With Flexible Headers

Branch ducts must have sufficient flexibility to accommodate potential sway movement of a flexibly hung duct header.

In particular, the review should identify lateral duct branches rigidly supported off long runs of duct with no axial restraints. The axial movement of the header could damage the branch duct. Similarly, a duct on sway type supports (such as rod hung trapeze or rod hangers) could swing and rupture a rigidly supported branch duct.

10.4.1.3 Evaluation for Pressure Boundary

Duct which has to maintain a pressure boundary must meet all of the screens for structural integrity (Section 10.4.1.2) and the following supplementary requirements.

10.4.1.3.1 Duct Joints and Seams Are of Rugged Type.

In addition to the criteria for structural integrity (Section 10.4.1.2), transverse joint configurations T-1 to T-16 (Ref. 113 Page 1-35) are outliers for pressure boundary review. Similarly, all longitudinal seams that are not groove or fillet welded (Ref. 114 Pages 8-1 through 8-6; Ref. 113 Page 3-5) are considered to be outliers for pressure boundary review.

10.4.1.3.2 Stiffeners and Joints Welded or Bolted to Duct

Duct stiffeners and joint reinforcements shall be attached to the duct by intermittent welds or by bolts with a maximum spacing of 12". For rectangular duct, the maximum distance of a weld or bolt from the duct edge is 2", (Ref. 113 Page 1-48).

Intermittent welds are typically staggered on alternate sides of the stiffeners and shall be 1" to 3" long (Ref. 114 Page 7-55).

10.4.1.3.3 Duct Gage, Stiffeners Sized to Resist Seismic Load

The Seismic Review Team shall verify the adequacy of the duct wall thickness (gage), stiffener size, and stiffener spacing in accordance with SMACNA (Ref. 113, 114, and 115), with the following provisions:

(a) The seismic accelerations generate uniform pressures acting on the duct in both + (internal pressure) and - (external pressure) directions. Due to the small deflections in duct wall, the scaled 2% damped accelerations must be used to evaluate stresses in duct walls.

(b) The stiffener deflection limits in SMACNA may be exceeded under seismic loads, provided the stiffener and the duct wall remain elastic. The SMACNA equations (Ref. 114 and 115) or the theory of plates and shells (Ref. 116) may be used for the stress analysis.

10.4.1.3.4 No Potential for Puncture of Duct Wall

Duct should not be supported on sharp edges or have point contacts with support members. Duct should be sufficiently restrained in the vertical and lateral directions, in accordance with the support span criteria for structural integrity, to avoid sliding or uplift impact.

10.4.1.3.5 Flexible Bellows Can Accommodate Motions

Where flexible bellows are provided, potential seismic displacements must be compared to bellows capacity. Alternatively, the bellows must be guided to preclude significant seismic differential movements.

10.4.1.4 Support Review

10.4.1.4.1 No Broken, Defective, or Degraded Hardware

Duct supports shall be visually inspected for adequate fabrication and maintenance. Signs of poor construction quality or subsequent degradation include: distortion, dislodged or shifted support members, missing brackets, nuts or bolts, unusual or temporary repairs, cracks in concrete, etc.

10.4.1.4.2 Support Member Capacity Exceeds Demand

The Seismic Review Team shall evaluate the sample support configuration(s) likely to have the largest demand/capacity ratio.

10.4.1.4.2.1 Seismic Demand

Ductile Supports: HVAC duct supports suspended from overhead or sidewalls (i.e. not supported from the floor) and which can be classified as ductile, as defined in the DOE Seismic Evaluation Procedure, must be evaluated for vertical capacity. The demand shall be based on 5 times the dead load in the downward direction (Ref. 107 page 39). A high vertical capacity provides considerable margin for horizontal earthquake loading.

Non-Ductile Supports: HVAC duct supports not classified as ductile, must be evaluated for vertical and horizontal (lateral or axial) loads. The scaled 7% damped peak spectral acceleration should be used to calculate applied loads, unless the spectral acceleration (see Section 5.2) at the duct span resonant frequency is determined.

$$F_a = W A_S$$

where:

W = tributary weight (lbs)
A_S = spectral acceleration (g)

Base-mounted supports represent a special type of non-ductile support. They are different than suspended supports in that base-mounted supports can become unstable when subjected to excessive lateral deflections or inelastic behavior since they don't have the pendulum restoring force attributes of suspended supports. Consequently, base-mounted support evaluations should include P-delta effects if there is the potential for base hardware slip. P-delta effects represent the second order increase in base overturning moment due to additional eccentricity of supported dead load during seismic deflections of the support. It is illustrated in Figure 10.4.1-3. Base plate flexibility (rotation) shall be postulated as applicable according to the following:

- shell expansion anchor slip of 1/8"
- channel nut slip of 1/16"
- clip angle bending

Additional discussion of base mounted support evaluations for P-delta effects is found in References 47 and 50.

10.4.1.4.2.2 Seismic Capacity

The support capacity shall be based on AISC (Ref. 81) including provisions to increase seismic allowable stresses by 1/3 (Ref. 81 Part 5 Section 1.5.6) and evaluation of potential for buckling.

HVAC duct supports consisting of rod hangers with fixed end connections shall be evaluated for fatigue (Ref. 47).

10.4.1.4.3 Anchorage Adequacy

For the bounding sample support configuration(s), the Seismic Review Team shall evaluate the support anchorage in accordance with Chapter 6 of the DOE Seismic Evaluation Procedure.

Anchor bolt installation (tightness) checks shall be performed for floor mounted supports as per Chapter 6 as well.

10.4.1.4.4 Support Details

Supports shall not include design details which have been a source of failure in past earthquakes such as beam clamps with no restraining strap, smooth channel nuts (without teeth or ridges) and cast-iron inserts.

10.4.1.5 Seismic Interaction Review

An evaluation shall be performed of potential seismic interaction hazards due to spatial proximity and differential motion between structures. Other seismic interaction evaluation considerations are identified in Chapter 7.

Free from Input by Nearby Equipment - Duct systems adjacent to other equipment should be evaluated for the consequences of interaction with moving items.

No Collapse of Overhead Equipment, Distribution Systems, or Masonry Walls - Duct Systems attached to or in the vicinity of unanchored components or unreinforced block walls should be evaluated for potential interaction.

Able to Accommodate Differential Displacements - Duct systems that span between different structures shall be evaluated to ensure adequate flexibility to accommodate relative movement of the structures.

10.4.1.6 Span Factors and Concentrated Weights

10.4.1.6.1 Span Factor for Rectangular Duct

Horizontal run of duct:

$$K_R = \left\{ S_h^2 R^4 W^2 \Big/ \left[(W^2/2) - W + 1) \right]^2 + S_v^2 H^2 \Big/ \left[\left(H^2/2 \right) - H + 1 \right]^2 \right\}^{1/2} + H \Big/ \left[(H^2/2) - H + 1 \right]$$

where:

S_h	=	horizontal spectral acceleration (see Section 5.2), lateral to duct (g)
S_v	=	vertical spectral acceleration (g) (see Section 5.2)
R	=	ratio of horizontal to vertical support spacing
W	=	width of duct (in)
H	=	height of duct (in)
K_R	=	span factor ($1/in^2$)

Vertical run of duct:

$$K_R = \left\{ S_{hW}^2 R^4 W^2 \Big/ \left[(W^2/2) - W + 1) \right]^2 + S_{hH}^2 H^2 \Big/ \left[(H^2/2) - H + 1 \right]^2 \right\}^{1/2}$$

where:

S_{hW}	=	horizontal spectral acceleration (see Section 5.2), parallel to side W (g)
S_{hH}	=	horizontal spectral acceleration (see Section 5.2), parallel to side H (g)
R	=	ratio of lateral support spacing in S_{hW} direction 2 to lateral support spacing in S_{hH} direction 1
W	=	width of duct (in)
H	=	height of duct (in)
L	=	maximum allowable support span in S_{hH} direction 1 (in)
K_R	=	span factor ($1/in^2$)

10.4.1.6.2 Span Factor for Circular Duct

Horizontal run of duct:

$$K_c = 1 + (S_v^2 + R^4 S_h^2)^{1/2}$$

where:

R	=	same as for horizontal rectangular duct
S_v	=	same as for horizontal rectangular duct
S_h	=	same as for horizontal rectangular duct
K_C	=	span factor (dimensionless)

Vertical run of duct:

$$K_c = (S_{h1}^2 + R^4 S_{h2}^2)^{1/2}$$

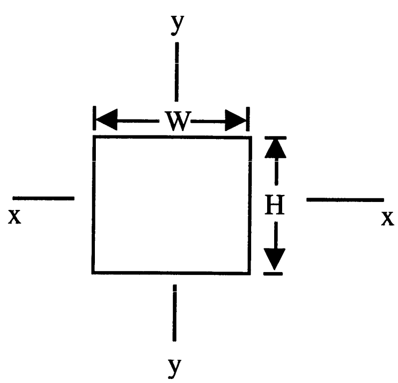
where:

S_{h1}	=	horizontal spectral acceleration (see Section 5.2) in direction 1
S_{h2}	=	horizontal spectral acceleration (see Section 5.2) in direction 2
R	=	ratio of lateral support spacing in direction 2 to lateral support spacing in direction 1
L	=	maximum allowable support span in direction 1 (in)
K_C	=	span factor (dimensionless)

10.4.1.6.3 Stress Equation

Seismic and weight bending stress in a duct due to its distributed weight and the weight of a heavy in-line (duct-mounted) component located mid-span is given below. For a horizontal rectangular duct, the stress is computed to be:

$$f_b = \left(wL^2/10 + PL/6\right)\left\{1 + \left[\left(a_H W/2I_{yy}\right)^2 + \left(a_v H/2I_{xx}\right)^2\right]^{1/2}\right\}$$



where:

f_b	=	total bending stress (psi)
w	=	distributed wt of duct (lbs/in)
L	=	length of duct span containing concentrated weight (in)
P	=	concentrated weight (lb)
a_H, a_v	=	horizontal and vertical accelerations (g)
W,H	=	width and height of duct (in)
I_{xx}, I_{yy}	=	moment of inertia of duct cross section (in^4). xx axis is parallel to width W; yy axis is parallel to height H (see figure above)
R	=	ratio of horizontal to vertical support spacing = 1

For a horizontal circular duct, the stress is computed using the above equation with W = H = D where D = outer diameter of duct (in).

10.4.1.6.4 Moments of Inertia for Rectangular Duct

Based on the SMACNA rectangular duct approximation of 4 corner angle sections (Ref. 114 Page 9-7), the moment of inertia is:

$$I_{xx} = 4\,t\,(H^2 - 2H + 2) \qquad (in^4)$$

$$I_{yy} = 4\,t\,(W^2 - 2W + 2) \qquad (in^4)$$

where:

t	=	duct thickness (in)
H	=	width of duct (in)
W	=	height of duct (in)

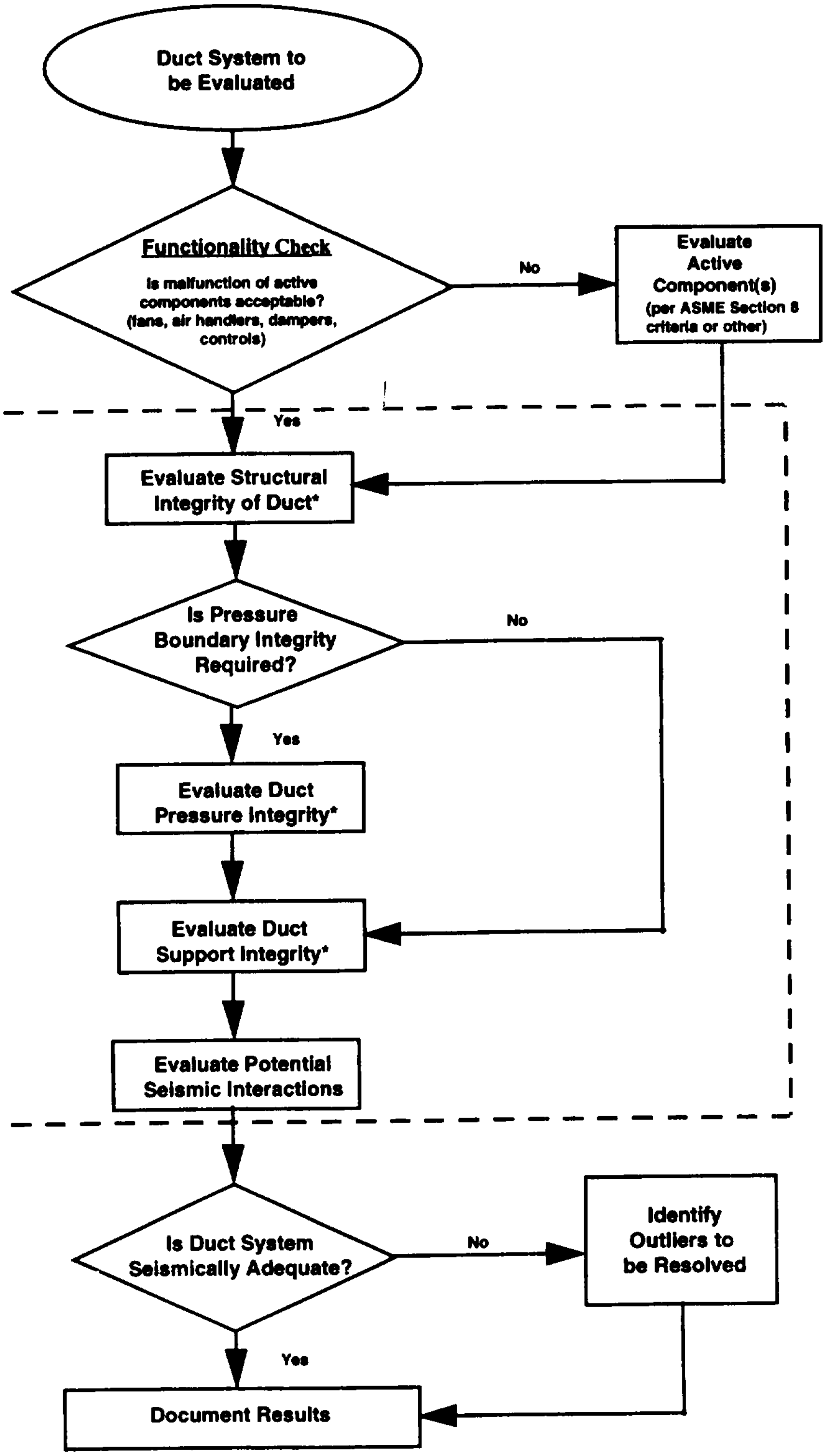
Note that the above equations include the 2" x 2" corners; hence, the H and W units must always be inches. If either W or H exceeds 72 in., the corresponding value used for calculating I_{xx} and I_{yy} shall be 72 in. Moment of inertia and section modulus calculations shall be based on dimensions $\leq$ 72 in. (Ref. 114 Page 9-7).

10.4.1.6.5 Moments of Inertia for Round Duct

$$I_{xx} = I_{yy} = 0.0491\,(D^4 - d^4) \qquad (in^4)$$

where:

D	=	outer diameter of duct (in)
d	=	inner diameter of duct (in)



* Requires limited analytical review in addition to field walkdown.

Figure 10.4.1-1 Logic Diagram for Duct System Seismic Evaluation

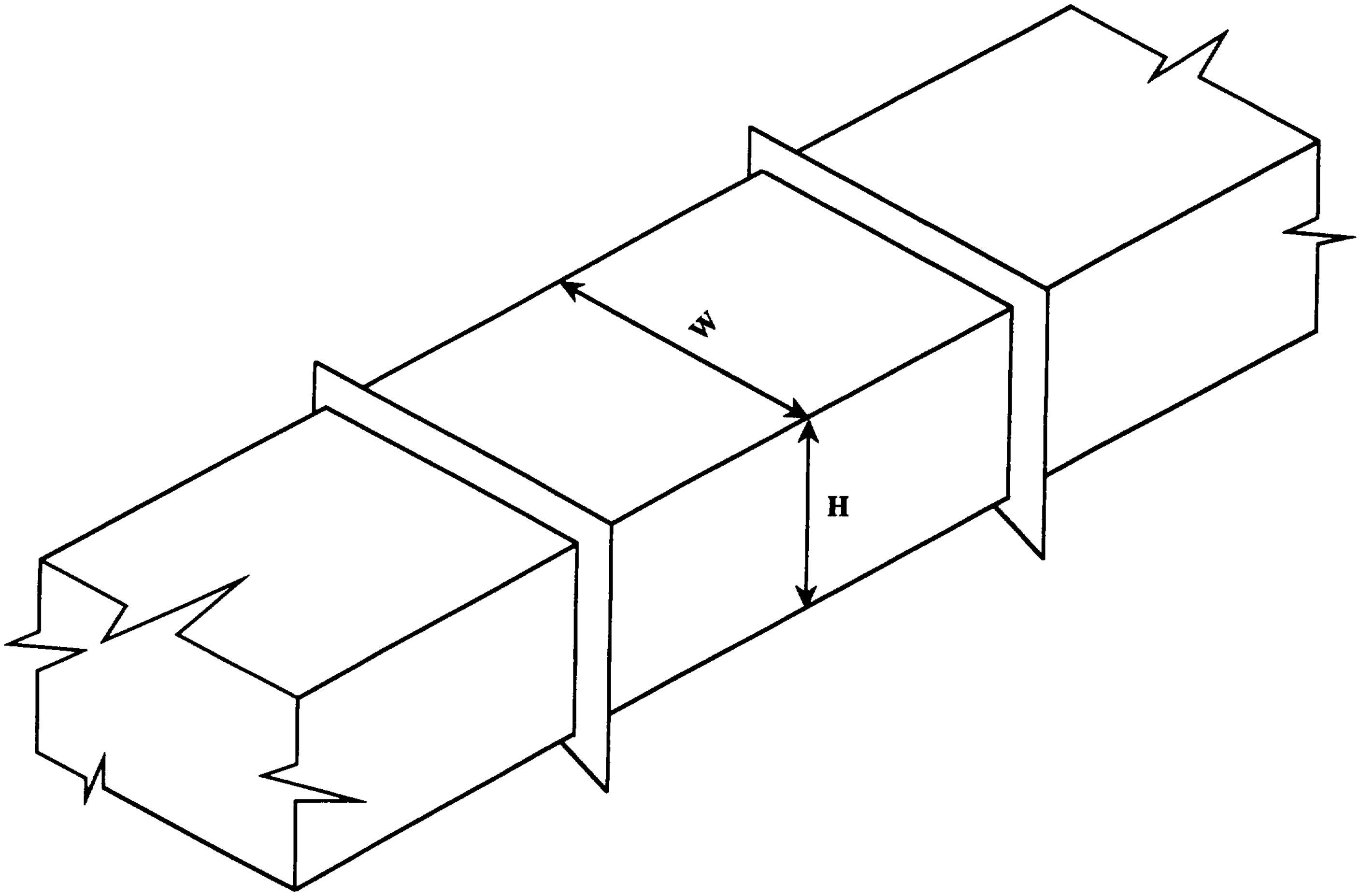
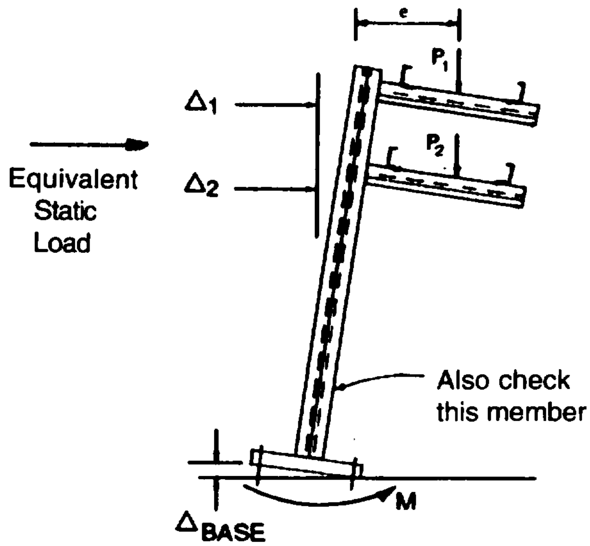
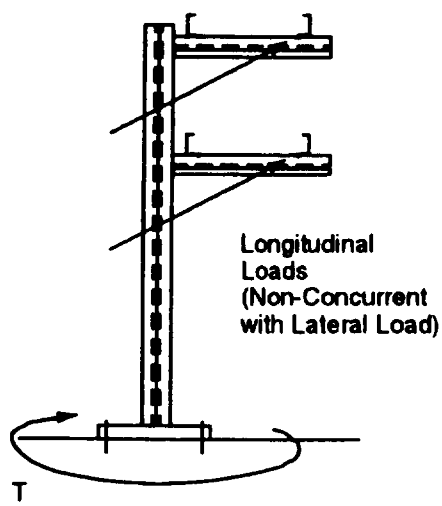


Figure 10.4.1-2 Typical Rectangular HVAC Duct Section



P-Δ EFFECTS FROM
BASE ROTATION ONLY



NEGLECT TORSION FOR
LONGITUDINAL LOAD

Figure 10.4.1-3 Floor Mounted Supports